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MOISTURE DETECTION IN ROOFS WITH CELLULAR PLASTIC INSULATION ----ETC(U)
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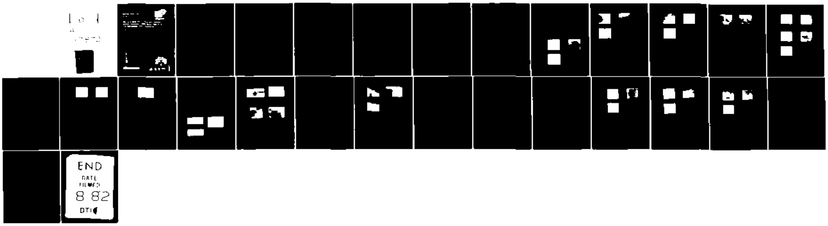

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New roofs with cellular plastic insulation and a bituminous built-up membrane were surveyed with a hand-held infrared camera to determine its effectiveness in detecting damp and wet insulation. Wet areas were found and defined with the help of 2-in.-diam. core samples. The results of the tests showed the infrared camera can be useful and effective as an inspection tool within the time constraints of the typical one-year warranty period. The tests also underlined the importance of core samples for verification.

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PREFACE

This report was prepared by Charles J. Korhonen and Barry A. Coutermarsh, Research Civil Engineers, of the Civil Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory.

The study was conducted under DA Project 4A762730AT42, Design, Construction and Operations Technology for Cold Regions, Task D, Cold Regions Design and Construction, Work Unit 015, Infrared Inspection of New Roofs Prior to Acceptance.

W. Tobiasson of CRREL and S. Kudzma and D. Passatino of the New York District, Corps of Engineers, technically reviewed this report.

The contents of this report are not to be used for advertising or promotional purposes. Citation of brand names does not constitute an official endorsement or approval of the use of such commercial products.

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CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM Metric Practice Guide (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	By	To obtain
inch	25.4*	millimeter
foot	0.3048*	meter
degrees Fahrenheit	$t_{°F} = (t_{°C} - 32)/1.8$	degrees Celsius

*Exact.

MOISTURE DETECTION IN ROOFS WITH CELLULAR PLASTIC INSULATION - WEST POINT, NEW YORK, AND MANCHESTER, NEW HAMPSHIRE

by

Charles J. Korhonen and Barry A. Coutermarsh

INTRODUCTION

According to the Army's Construction Inspector's Guide (U.S. Army 1965), an inspector is to assure that approved materials are used and properly applied before any roofing system is accepted by the Army. Unfortunately visual inspections usually cannot determine if a roof membrane is watertight. Even a properly applied membrane built with proper materials can have a few flaws from the day it is built. Leaks may not manifest themselves within the building until months or years after construction, especially if a vapor retarder is present in the roofing system. Although leakage problems may be caused by poor workmanship, the owner may have no knowledge of such a problem during the customary one-year workmanship warranty period.

Infrared cameras have been quite successful in finding wet insulation in roofs containing rigid board insulations of fibrous glass, fiberboard and perlite (Tobiasson et al. 1977). Since these insulations become wet rather rapidly when subjected to moisture in the presence of a temperature gradient, it has been well established that early detection of flaws during the warranty period is possible (Tobiasson and Rand 1979). However, many of our newer roofs contain cellular plastic insulations, most of which are much more resistant to moisture. Ironically, the ability of most cellular plastics to resist rapid wetting can make early detection and location of flaws difficult. The objective of this field study was to determine if an infrared camera could find roof moisture during the one-year warranty period in built-up roofs containing cellular plastic insulation. The technique used to survey roofs for wet insulation with an infrared camera is discussed by Korhonen and Tobiasson (1978).

Eight newly constructed roofs containing cellular plastic insulation were selected for study at the U.S. Military Academy, West Point, New York, and at Grenier Field, Manchester, New Hampshire. We surveyed each

roof twice with an AGA Thermovision 750 infrared camera and took several 2-in.-diam. core samples to verify infrared findings. Core samples were weighed, oven dried at 110°F and reweighed to determine water contents (expressed in this report as a percentage of the weight ratio of water to dry insulation). Core sample moisture contents are tabulated on the plan view of each roof presented in this report.

ROOFS AT WEST POINT

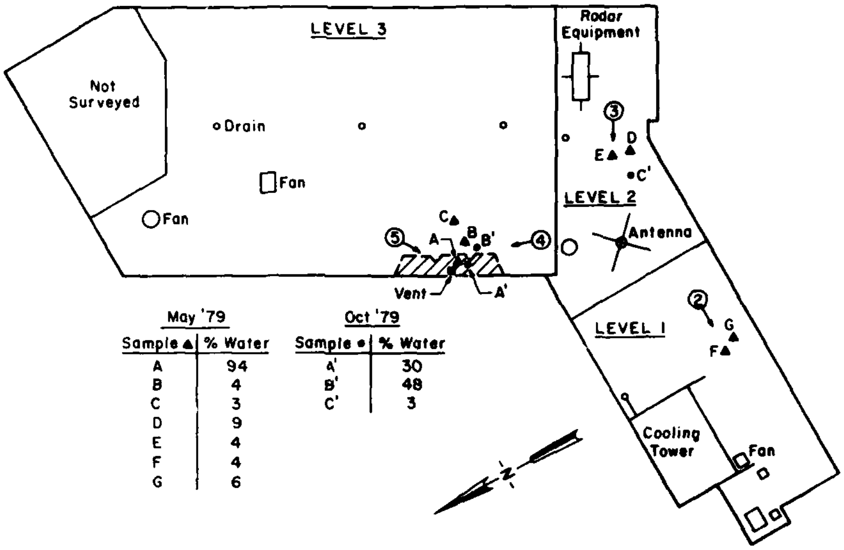
At the U.S. Military Academy, four buildings (753, 751, 745A, 667A) were re-roofed with 2-1/4-in.-thick urethane board insulation and a gravel-covered bituminous built-up membrane. In each case the existing membrane and insulation were removed and a vapor retarder was applied to the structural concrete deck before the new urethane insulation and membrane were installed. Warranties for Buildings 753, 745A and 667A started on 22 December 1978 and on 19 September 1978 for Building 751.

We surveyed these roofs on the nights of 1 May 1979 and again on 17 October 1979. Although three roofs (Buildings 753, 667A-west and 667A-east) contained wet insulation, no leaks were reported in any of the four buildings. The vapor retarder prevented water from entering the building and allowed it to spread unnoticed within the insulation.

A Delmhorst Model BD-7 moisture probe and a Moisture Register Model PM-8F capacitance meter were used in conjunction with our coring operation to cross-check moisture conditions.

Building 753

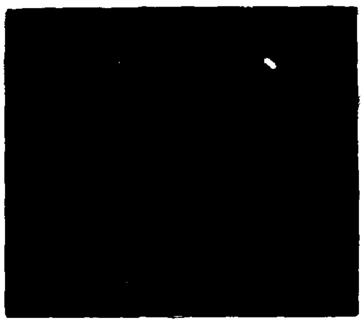
During the May and October surveys the thermal image of each level of the roof of Building 753 (Fig. 1) was mottled (i.e. with thermally light and dark areas blending into one another). By scraping the gravel cover and taking samples F and G (Fig. 2) in May we determined that the mottling was caused by varying gravel thicknesses and not wet insulation. Thick layers of gravel store more solar heat and remain warmer longer than thin gravel layers. Figure 2c, although mottled, does not have as pronounced mottling as Figure 2a, indicating less solar effect in October. The two black areas in Figure 2c were caused by patches at F and G.



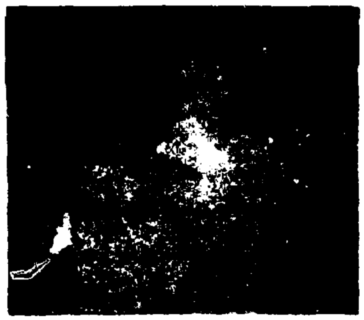
May '79 Sample ▲	% Water
A	94
B	4
C	3
D	9
E	4
F	4
G	6

Oct '79 Sample ●	% Water
A'	30
B'	48
C'	3

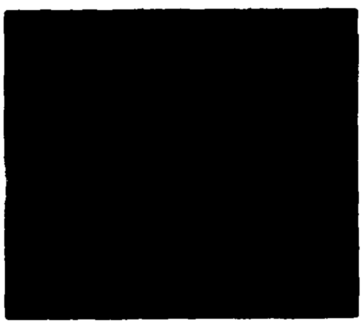
Figure 1. Plan view sketch of Building 753, West Point. For this and all other building sketches in this report, a circled number with an arrow indicates the location and viewing direction of a particular figure.



a. May 1979 thermogram.

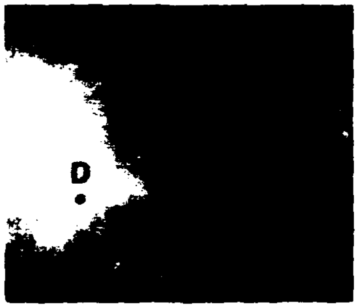


b. May 1979 photograph.



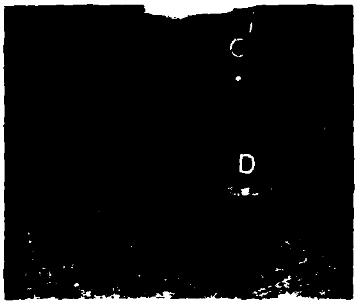
c. October 1979 thermogram.

Figure 2. Building 753, first level. The entire roof had a mottled appearance as shown in these two thermograms.



a. May 1979 thermogram.

b. May 1979 photograph.



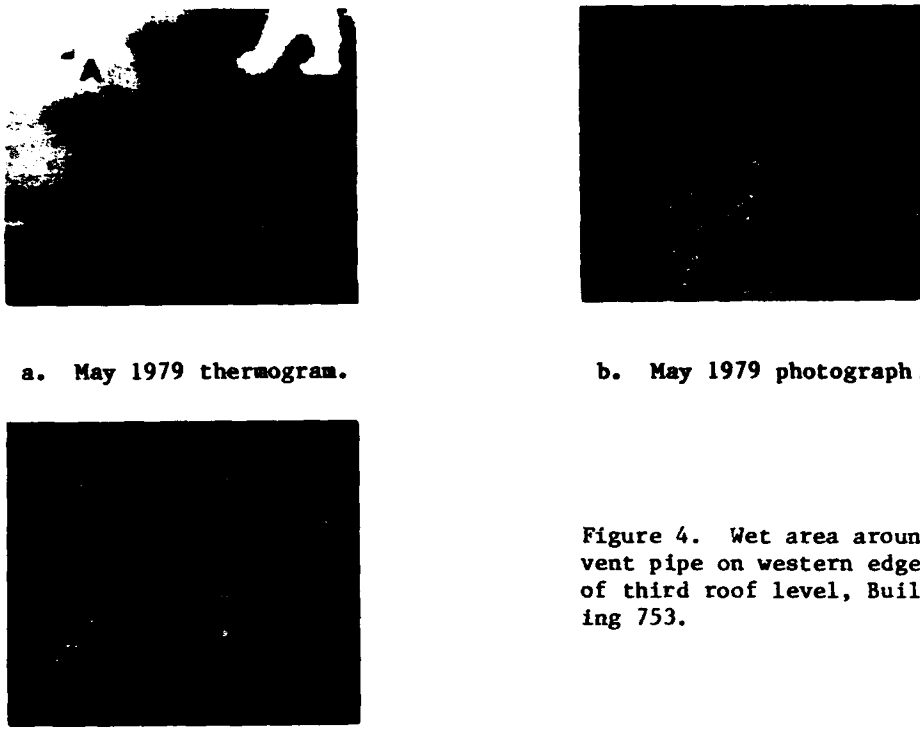
c. October 1979 thermogram.

Figure 3. Building 753, second level. One bright thermal anomaly was detected.

On the second level of this three-level roof, one relatively bright area was detected (Fig. 3) that did not contain thick gravel. Core samples D and E taken in May showed that the insulation contained only 9 and 4% water, respectively, and that the built-up membrane at D was thicker than at E (1/2 vs 3/8 in.).

In October this thick area, although readily detectable, was not as bright (Fig. 3c) and sample C', taken from the area of the bright spot, contained only 3% moisture. The increased membrane thickness is considered to be the major cause of the bright area in Figure 3 because a thicker membrane can store more of the day's heat than can a thinner membrane. Since no other indications of moisture were detected, we feel that the second roof level contains no moisture entry points.

A bright area was present along the western edge (Fig. 4a) of the third roof level. If the anomaly had been only heat radiating onto the roof from the parapet wall it would have blended into the roof a short distance (2 to 3 ft) from the wall. Figure 4 shows the edge of this



a. May 1979 thermogram.

b. May 1979 photograph.

c. October 1979 thermogram.

Figure 4. Wet area around vent pipe on western edge of third roof level, Building 753.

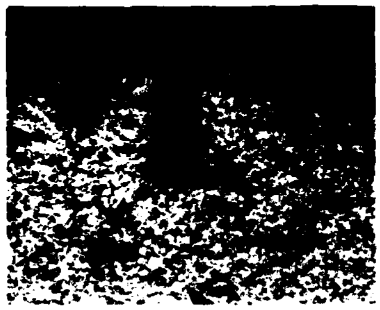
anomaly to be well-defined and stepped, which is a strong indication of wet insulation. Sample A contained 94% water. Figure 5 shows that a guy wire installed in December 1978 from a nearby antenna had pulled the vent pipe flashing from the roof, thereby creating the moisture entry point for this area. The wire was removed and the flashing repaired sometime after May 1979.

In comparison to Figure 4a, Figure 4c (taken in October) shows that the thermal anomaly near the vent pipe is no longer as well-defined. It blends gradually into the roof. Sample A' shows a loss in water content from May near the vent pipe, but sample B' shows that moisture has increased during this time period just a short distance away. Based on this pattern it appears that the entrapped moisture has spread out into the insulation.

Building 751

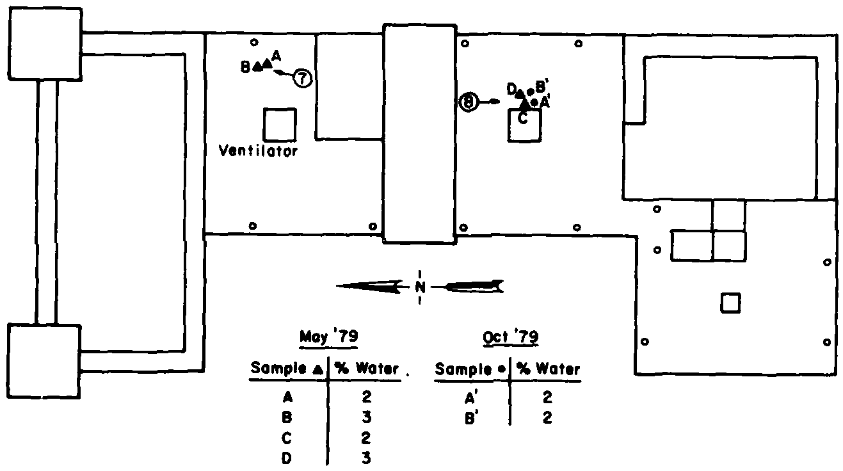
A plan view of the roof of Building 751 is shown in Figure 6. The

a. May 1979.



b. October 1979.

Figure 5. Area where tension from a guy wire pulled vent pipe flashing from the roof. It was patched shortly after our May survey.



Sample ▲	% Water
A	2
B	3
C	2
D	3

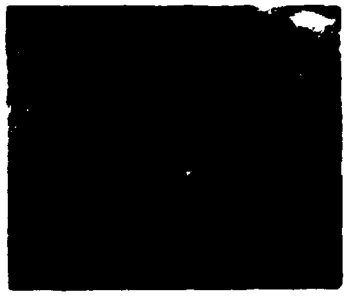
Sample •	% Water
A'	2
B'	2

Figure 6. Plan view of Building 751.

thermal mottling on most of this roof was related to varying gravel thickness, but mottling was also observed in a few areas where the gravel thickness was uniform. Representative samples A and B (Fig. 7) contained only 2 and 3% water, respectively; therefore the thermal mottling was not considered moisture-related. Since both A and B had identical membrane thicknesses (3/8 in.), we expect that slight differences in the bitumen flood coat thickness caused the slight thermal mottling. Since the gravel and a portion of the flood coat are normally spudded off before coring, no measurements were obtained to verify this contention.

Figure 8 shows a bright thermal anomaly that appeared to be caused by

a. May 1979 thermogram.



b. May 1979 photograph.

Figure 7. Sample areas A and B, Building 751.

a. May 1979 thermogram.

b. May 1979 photograph.

c. October 1979 thermogram. Thermal anomaly seems to have grown since May.

Figure 8. Sample areas C and D, Building 751.

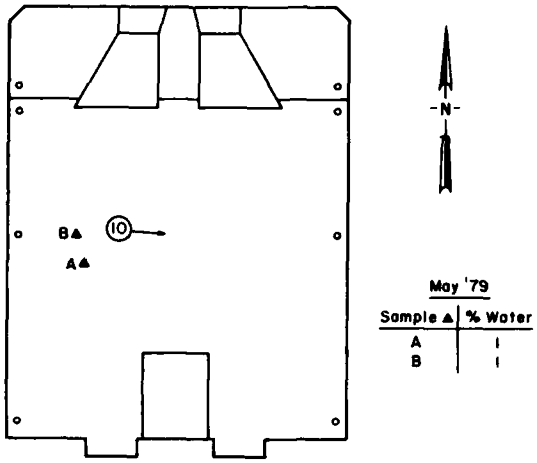


Figure 9. Plan view of Building 745A.

hot air blown onto the roof from the neighboring ventilator. But since we could not feel any movement of air from the ventilator, core samples C and D were taken; they contained only 2 and 3% water, respectively. A similar situation occurred in October except that the hot spot seemed to be somewhat larger and samples A' and B' again proved the hot spot to be dry.

Based on the above information Building 751 appears to be free of wet roof insulation.

Building 745A

A plan view of the roof of Building 745A is shown in Figure 9. The thermal mottling, to which we had by now become accustomed, was present on this roof and could be attributed to varying gravel (or bitumen) thicknesses and not moisture. We did note that the mottling was somewhat fainter by the time we surveyed this roof. Figure 10 shows that the northern half of this roof was thermally brighter than the southern half, but that samples A and B taken from the southern and northern half, respectively, were dry. We were unable to gain access to the space below the roof but speculate that this thermal pattern was caused by room to room temperature differences.

No wet insulation was found in this roof.

Building 667A

Building 667 is composed of several sections. We surveyed the roofs

a. May 1979 thermogram. We saw the same thermal image in October 1979.

b. May 1979 photograph.

Figure 10. Roof of Building 745A, showing thermal division, perhaps caused by rooms of different temperature below the roof.

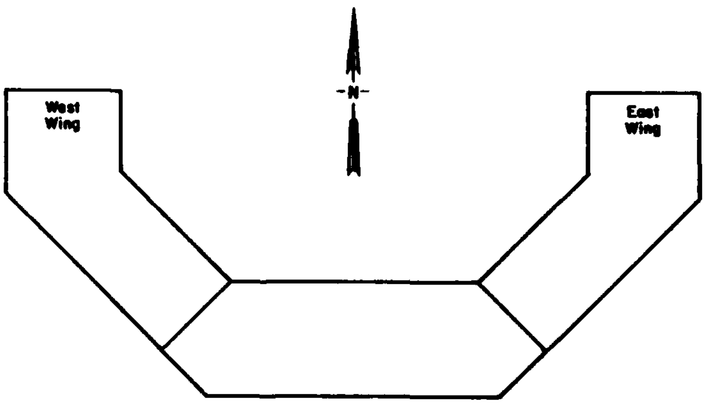


Figure 11. Section A, Building 667.

of the west and east wings of section A, which are shown in plan view in Figure 11. The west wing roof membrane was installed prior to December 1977 and the east wing membrane was installed prior to May 1978. Due to some unfinished work, the warranty for the roofs of these wings did not commence until December 1978.

Several thermally bright areas were found on each wing. Core samples showed that they were areas of wet insulation. Most of this moisture can probably be traced to flashing problems. The counter-flashing shown in Figure 12 was not installed until six months after the roof membrane was finished. When the flashing was finally installed, the sealant and bond-breaker rod between the flashing and the wall began to fall out and had to

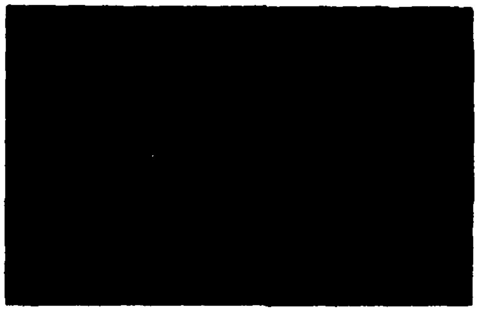


Figure 12. Parapet flashing that was not installed immediately after the roof was laid. Arrow shows the bond-breaker rod falling out of joint (May 1979 photograph).

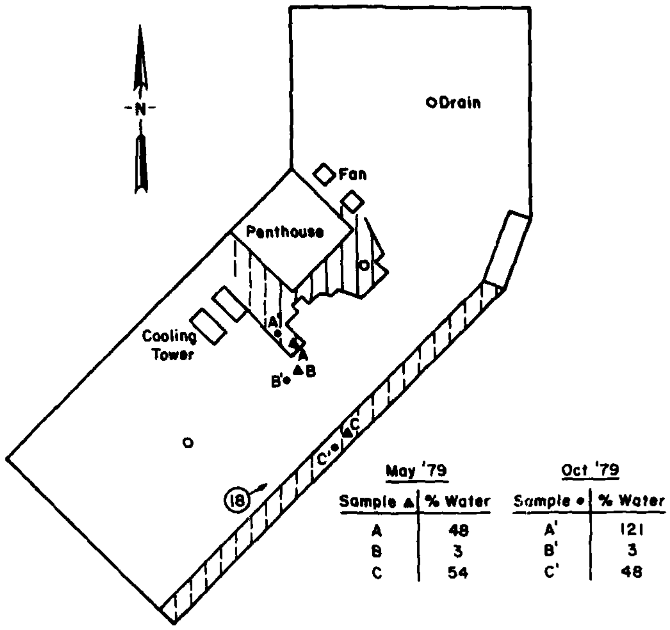
be reinstalled in August 1979. This sequence of events and the infrared results suggest that water entered this roof there. Details are presented below.

<u>West Wing</u>

Figure 13 shows the boundaries of several well-defined bright areas detected in May. Samples A, C and D taken from those areas were quite wet. However, samples B and E, located outside the bright areas and assumed to be dry, also contained moisture (61 and 37%, respectively). Thus it became clear that a larger area was "wet." Tobiasson and Ricard (1979) show that these moisture contents mean approximate losses in insulating value of 25% and 10%, respectively. Normally we would have had to return to this roof and resurvey it, but since a second survey was planned for October we waited until then.

By October the bright areas had grown to include points B and E. However, Figures 14 and 15 show that they were not of uniform brightness, which indicates varying water contents. Confirmation of this came from sample A', taken from a dark area near point A, and sample D', taken from a bright area near point E. Sample A' contained 8% water and D' contained 118% water.

Samples B and E taken in May certainly demonstrate the importance of taking core samples, especially on new roofs containing slow-wetting, cellular plastic insulation.



May '79 Sample ▲	% Water
A	48
B	3
C	54

Oct '79 Sample ●	% Water
A'	121
B'	3
C'	48

Figure 13. Plan view of Building 667A-west. Open hatching indicates areas of nonuniform brightness (mottling). Solid lines depict brightness (mottling). Solid lines depict May boundaries and dashed lines depict October boundaries.

a. May 1979 thermogram.

b. October 1979 photograph. Dashed paint line is extent of wet area found in May. Solid line is October.

c. October 1979 thermogram.

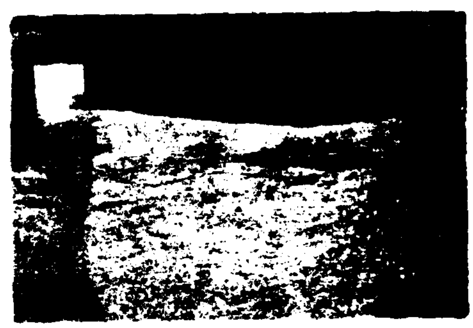
Figure 14. View of sample areas C, D, D' and E, Building 667A-west.

a. October 1979 thermogram. Arrow points to drain.

b. October 1979 photograph. The solid lines depict wet areas found in May and dashed lines are October boundaries.

Figure 15. View of sample areas A, A' and B'. Building 667A-west.

a. October 1979 thermogram.



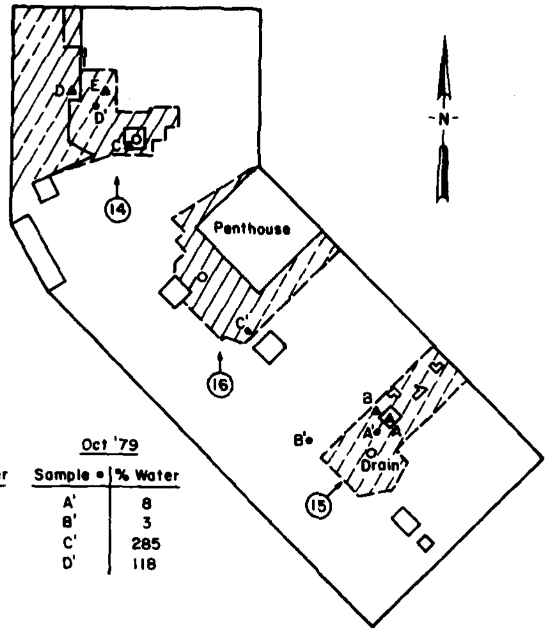
b. October 1979 photograph.

Figure 16. Wet areas surrounding penthouse on Building 667A-west.

Figure 16 shows a very bright thermal anomaly surrounding the penthouse in October. Within this area sample C' contained 285% water. We did not detect a thermal anomaly there in May.

East Wing

A plan view of this area (Fig. 17) shows two wet areas. Two thermograms and one photograph are shown in Figure 18 of the wet area bordering the southeast parapet. No appreciable change was detected in the shape or size of either wet area between the May and October surveys, suggesting that repairs to the counterflashings have been successful in preventing further wetting of this roof. Core samples indicate that little or no drying has taken place.



May '79 Sample ▲	% Water
A	152
B	61
C	290
D	562
E	37

Oct '79 Sample •	% Water
A'	8
B'	3
C'	285
D'	118

Figure 17. Plan view of Building 667A-east. Open hatching indicates areas of nonuniform brightness (mottling).

Use of capacitance and electrical resistance meters at West Point

Tobiasson and Korhonen (1978) state that no nondestructive roof moisture detection system is reliable enough by itself or by cross-checking with another type of nondestructive system to eliminate the need for core samples of the membrane and insulation. Since these statements are based on tests of roofs that did not contain cellular plastic insulations, we decided to evaluate two instruments for cross-checking infrared findings during the West Point survey. We tested a Moisture Register Model PM-8F capacitance instrument and a Delmhorst BD-7 electrical resistance probe. The capacitance test is nondestructive but the membrane must be punctured before the electrical resistance probe can be inserted into the roof.

Capacitance meter. The PM-8F measures the energy that is lost when a material is placed into an alternating electric field. The magnitude of this loss is generally related to the number of polar molecules in the material, and water, being highly polar, can significantly affect PM-8F measurements. All capacitance readings were taken after the gravel was

a. May 1979 thermogram.

b. October 1979 photograph.

c. October 1979 thermogram.

Figure 18. View of wet area along southeast parapet wall, Building 667A-east.

removed from an approximately 12- x 12-in. area of roof to eliminate variations in readings caused by different gravel thicknesses.

Electrical resistance probe. The resistance probe measures the flow of direct current between two electrodes. As the conductivity of the insulation increases, the readings on the resistance probe increase. Generally, an increase in the water content of the insulation increases its electrical conductivity and the meter reading. The elecrical probe readings were obtained by first piercing two holes through the membrane with an awl and then inserting the probes to about the midpoint of the insulation.

Capacitance and electrical resistance results. There are a significant number of inconsistencies between the readings from the capacitance meter and resistance probe in Table 1. At some locations where core samples show the insulation to be wet (i.e. Building 667A-west, samples A, B, C, D, and E, and C' and Building 667A-east, sample A'), probe and capacitance

Table 1. Water content vs capacitance and electrical resistance meter readings, West Point, New York* (measurements are relative but have no units).

Bldg	Sample	May 1979 Meter Reading Cap	Elec res	% Water Insul	Memb	Sample	October 1979 Meter Reading Cap	Elec res	% Water Insul	Memb
753	A	>200†	0	94	5	A'	197	0	30	4
	B	114	0	4	1	B'	189	0	48	4
	C	138	0	3	1					
	D	>200†	0	9	3	C'	121	0	3	1
	E	148	0	4	1					
	F	110	0	4	2					
	G	104	0	6	3					
751	A	150	0	2	1					
	B	167	0	3	0					
	C	180	0	2	1	A'	131	0	2	1
	D	165	0	3	1	B'	105	0	2	1
745A	A	95	0	1	3					
	B	82	0	1	0					
667A-west	A	>200†	14	152	11	A'	131	0	8	2
	B	>200†	15	61	9					
	C	>200†	25	290	9					
	D	150	28	562	37					
	E	170	17	37	4	D'	>200†	-	118	12
						B'	90	0	3	2
						C'	>200†	21	285	7
667A-east	A	137	0	48	7	A'	108	12	121	2
	B	95	0	3	2	B'	78	0	3	2
	C	>200†	0	54	3	C'	98	0	48	3

* Readings taken from the same area of the roof during the May and October surveys are presented on the same line. For example, C and A' on Building 751 were taken adjacent to each other.
† These readings are beyond the capability of the instrument when set at medium sensitivity.

readings are high, as would be expected. But at other wet locations (i.e. Building 753, samples A, A' and B' and Building 667A-east A, C and C) the probe readings were low while the capacitance readings were high. The high capacitance readings are as expected because of the water that was present in each sample. The low resistance probe readings are suspected to be caused by the water being located at the bottom of the insulation and not at the midpoint, where we obtained the probe readings. This suspicion was confirmed at sample location C on Building 667A east. By probing deeper in that location, we found that the probe reading significantly increased. At all locations where the core samples indicated the insulation was dry, probe readings also indicated it was dry.

Although most capacitance readings reflected increased moisture conditions, a notable exception occurs on Building 753 where the insulation in sample D was dry but a very high capacitance reading was obtained. We can offer no explanation for this, but this type of inconsistency shows the difficulty in establishing a wet/dry threshold with a capacitance meter. Even though each roof was constructed of the same materials, the dry limit appears to vary from a high of between 148 and 189 on Building 753 to a low of between 95 and 98 on Building 667A-east.

The electrical probe readings show a somewhat stronger tendency to increase with increasing moisture in the insulation, as illustrated by the probe readings on Building 667A-west (i.e. samples A, C', C and D). However, exceptions to this trend can be found in Table 1. Some of these inconsistencies can likely be explained by a nonuniform distribution of moisture in the insulation with the greatest concentration of moisture near the bottom.

Table 1 does not show a clear relationship between instrument readings and water contents, thus demonstrating that there can be difficulties in detecting roof moisture with these instruments. This convinces us that core samples are essential for verifying the findings from moisture surveys on roofs with cellular plastic insulations, as well as with other insulation types.

ROOFS AT MANCHESTER, NEW HAMPSHIRE

Three Army Reserve buildings (Maintenance Garage, Motor Pool Garage, and Main Building) at Grenier Field in Manchester, New Hampshire, were re-roofed in November 1978. After the existing bituminous built-up

membrane and insulation were removed, the Maintenance Garage and the Main Building were re-roofed with 2-1/4 in. of urethane insulation and a gravel-covered bituminous built-up membrane. A similar operation was performed on the Motor Pool Garage except that a urethane-perlite composite board insulation was used. Because of ponds of water, we could not thermographically survey the Maintenance Garage. (Tobiasson et al. [1981] surveyed this roof in August 1980 and found much of the insulation to be wet.)

The roofs of the Motor Pool Garage and the Main Building were surveyed with the infrared camera in May 1979 and again in November 1979. We found no wet insulation on these two roofs. Several 2-in.-diam. core samples were taken to verify infrared findings.

Motor Pool

A plan view of the roof of the Motor Pool Garage is shown in Figure 19. Thermally this roof was mottled during both the May and November surveys (Fig. 20). Samples A and B taken in May and samples A' and B' taken in November were dry, which convinced us that this mottling was not moisture-related. The bright areas in the Figure 20 thermograms correspond to areas of thicker gravel. Since all core samples were dry and no other thermal anomalies were detected, we feel that this roof contains no wet insulation.

Main Building

A plan view of the Main Building's roof is shown in Figure 21. Varying gravel thicknesses created the thermal mottling detected on this

May '79

Sample ▲	% Water
A	2
B	2

Nov '79

Sample •	% Water
A'	2
B'	2

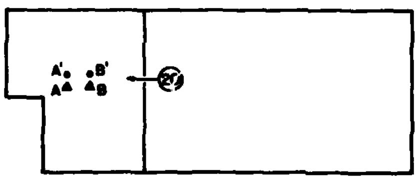
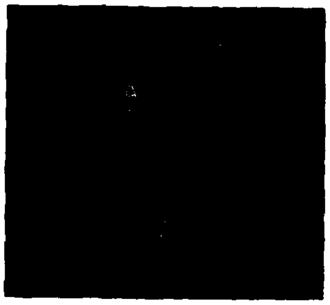


Figure 19. Plan view of the Motor Pool Garage at Grenier Field.



a. May 1979 thermogram.

b. May 1979 photograph.

c. November 1979 thermogram.

Figure 20. View of sample areas A, A', B and B', Motor Pool Garage.

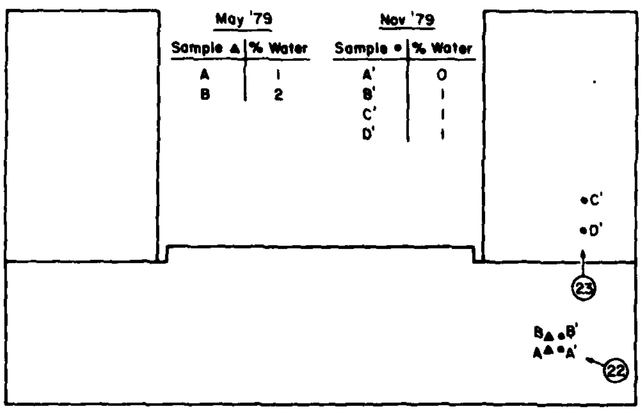
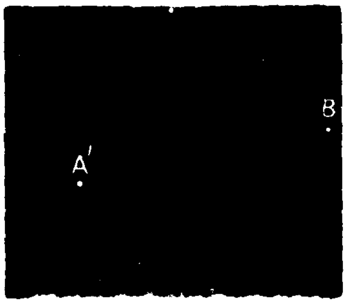


Figure 21. Plan view of the Main Building at Grenier Field.

a. May 1979 thermogram.

b. May 1979 photograph.



c. November 1979 thermogram.

Figure 22. View of sample areas A, and B, Main Building. (The dark lines and circles in a and c are spray-painted markings for identifying the boundaries.)

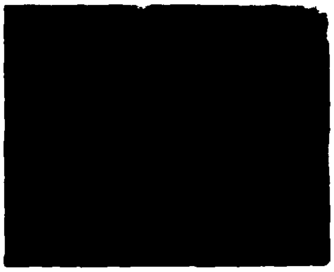
roof during May and November. Two bright areas stood out from the mottling but core samples showed them to be dry.

Figure 22 shows a portion of a bright strip that ran down the center of this roof. The gravel, membrane and insulation thicknesses were the same for samples A and B taken in May 1979 and A' and B' taken on November 1979. Visually, the roof surface appeared to be uniform in this area. It is likely that the bitumen flood coat was heavier on this strip, thereby causing it to appear brighter, but no measurements were obtained to verify this explanation.

The Figure 23 thermograms show an area of roof that was thermally brighter in May than in November. Such a thermal change could indicate a change in moisture content in the insulation. However, core samples C' and D' showed the insulation to be dry and the built-up membrane to be of uniform thickness. By scraping the gravel, we determined that the bright area had a thicker gravel cover. Thus the extra solar heat stored in this thicker gravel caused it to appear brighter to the infrared camera.

a. May 1979 thermogram.

b. November 1979 photograph.



c. November 1979 thermogram.

Figure 23. View of sample areas C' and D', Main Building.

Since all samples on this roof were dry and no other indications of moisture were detected, we feel that the Main Building contains no wet roof insulation.

CONCLUSIONS AND RECOMMENDATIONS

We surveyed seven new roofs with an infrared camera to determine the feasibility of using such equipment for detecting leaks in newly built roofing systems that contain urethane insulation. Of the seven new roofs studied, wet insulation was detected in three of the roofs before their one-year warranty expired, thus demonstrating that new roofs have construction defects and that an infrared camera can be used to find wet cellular plastic insulation a few months after construction.

The surveys of Buildings 753 and 667A at West Point showed some difficulty in consistently detecting low levels of moisture in cellular plastic insulation. At times, thermal mottling made it difficult to

identify and map out areas containing damp insulation, but this mottling became less confusing when additional core samples were examined. It was also shown that readings from resistance moisture probes must be made at points throughout the entire depth of the roof insulation because the urethane insulation was often damp near the roof deck but dry elsewhere.

West Point

Buildings 745A and 751 appear to have good roofs with no wet insulation present. No further action other than normal maintenance is recommended for these roofs.

In May Building 753 contained wet insulation around a dislodged vent pipe flashing. Since the flashing was repaired and the wet area is relatively small, the overall thermal efficiency of the roof is still high. Therefore, no further action is recommended on this roof, other than normal maintenance.

Building 667A-west had areas of wet insulation around the penthouse and the northwest corner. The thermal efficiency of the insulation in these areas ranged from 65% of its dry R-value to less than 30% of its dry R-value. We recommended that the insulation and membrane in these areas be removed and replaced under the terms of the warranty. A third area on 667A-west, although not as thermally poor as the above, also contained moisture. The insulation should also be replaced in that area.

The roof on Building 667A-east had two areas of wet insulation. These areas along the southeast parapet wall and around the penthouse should be replaced under terms of the warranty.

Since both the east and west roofs of Building 667A had wet insulation around the penthouse and along parapet walls, the flashing and masonry work should be inspected for potential water entry points.

Grenier Field

The two roofs we were able to survey at Grenier Field appeared to be in good condition; no wet insulation was found. No further action other than normal maintenance is recommended there.

FOLLOW-UP

A return call to West Point revealed that the roofing contractor repaired some membrane blisters under terms of the roofing contract in areas we determined to be wet on Building 667A-west. Unfortunately no wet insulation was removed because it was felt that water was entering the roof system through the parapet masonry and thus was not the responsibility of the roofer. Had defects been found in the roof membrane, the roofing contractor would have been obligated under terms of the warranty to replace the wet insulation and repair the defects.

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